

## THE IMPACT OF WIND FARMS IN NATURAL AREAS: OBJECTIVE AND SUBJECTIVE APPROACH

PACS no. 43.50.Rq

Aletta Francesco; Maffei Luigi; Masullo Massimiliano; Sorrentino Francesco; Di Gabriele Maria  
Second University of Naples  
Department of Architecture and Industrial Design  
Via San Lorenzo ad Septimum,  
81031 Aversa (CE), Italy  
E-mail: francesco.aletta@unina2.it

### ABSTRACT

Due to the necessity of large parts of land, Wind Farms are often placed in open natural areas. Despite the fact that Wind Farms are represented as environmentally friendly, they frequently encounter public resistance and elicit an increasing number of complaints. In order to identify and assess the impact of a Wind Farm on residents, the results of a noise/meteorological monitoring campaign and an auditory test on two groups of subjects (exposed and non-exposed to wind turbine noise) carried out in two different countryside sites in Campania (Italy) are discussed.

### RESUMEN

Debido a la necesidad de utilizar grandes espacios, a menudo los parques eólicos se colocan en contextos naturales. A pesar del hecho de que la energía eólica se considera una forma de energía respetuosa con el medio ambiente, las turbinas encuentran con frecuencia con la resistencia del público y provocan un número creciente de quejas. Con el fin de identificar y evaluar el impacto de un parque eólico para los residentes, se presentan los resultados de un monitoreo meteorológico y de ruido y una prueba auditiva en dos grupos de sujetos (expuestos y no expuestos a ruido de turbinas de viento) que se hicieron en dos distintos sitios en Campania (Italia).

### INTRODUCTION

Wind energy represents one of the most important renewable resources. Nevertheless, Wind Farms (WFs) frequently encounter public resistance and several studies reported that people exposed to WFs' noise complaint about sleep disturbance and adverse health effects [1,2]. Due to the necessity of using large parts of land, WFs are often placed in traditionally rural and natural areas, where their installation could lead to significant changes in terms of soundscape and landscape.

From the acoustic viewpoint, Wind Turbines (WTs) are a very specific source of sound that is barely comparable with other noise source or set of noise sources. They have special acoustic characteristics that can be described as modulating sound or as a tonal complex. These sounds are often of low amplitude and are shifting continuously in character; Thorne [3] underlines that "character" is what human perception is primarily responding to, rather than sound level. Research [4] confirmed that, although noise may be one critical factor for the public acceptance of WTs, no clear relationship was found between annoyance and equivalent noise level. The hypothesis for their study was that different sound characters in the noise, not fully described by the equivalent noise level, were of importance for annoyance and noise perception. What can be mostly expected is that, in any natural context, WTs are highly visible and their visual impact could be increased due to the size of the object in the field of view [5] and the coherence of the object with respect to its environment [6]: a technological element in a quite natural background could generate some perceptual contrast. Pedersen and Larsman [6] explain that for this reason, people exposed to WT noise in their home environment could be expected to be exposed also to visually annoying stimuli from the same source.

The methodologies for the noise assessment of WTs at the receiver points are widely described by national legislations. Typically, they plan to carry out measurements at the receiver, when the WTs are functioning and when they are not, immediately once they have been stopped [7]. In this way the background noise may be assessed, considering the same weather conditions and it is possible to obtain the contribution of the WTs noise from the comparison of the Background Noise Level and the Environmental noise Level.

Nevertheless, to overcome the technical/economical problems of switching-off the WTs, an alternative method was proposed by Hessler [8]. Two simultaneous measurements must be carried out: "on-site", as measurement of the Environmental Noise Level, and "off-site", as the likely Background Noise Level on-site. The requirements to select "off-site" points for measurements are: 1) far enough, where WTs noise is negligible; 2) close enough to be representative of the area [8]. The WTs' noise contribution is represented by the difference between the Environmental Noise Level and Background Noise Level. However the perception of the WT noise, changes significantly according to the wind speed, intensity and direction. The statistical analysis of data provided by the contemporary measurements of noise and meteorological parameters can help to observe some objective aspects of the perception in main range of frequency of the noise radiated by the WT.

From the subjective perspective, different non-acoustical factors or personal and behavioural factors could affect the perception of WT noise and its impact. An interesting cross-sectional study by Pedersen and Persson Waye [9] was carried out in seven areas in Sweden across dissimilar terrain and different degrees of urbanisation. Perception and annoyance due to WT noise in relation to SPLs was analysed with regard to dissimilarities between the areas. Perception and annoyance were associated with terrain and urbanisation: (1) a rural area increased the risk of perception and annoyance in comparison with a suburban area; and (2) in a rural setting, complex ground (hilly or rocky terrain) increased the risk compared with flat ground. Annoyance was associated with both objective and subjective factors of WT visibility, and was further associated with lowered sleep quality and negative emotions.

Moreover, in recent times, Maffei et. al [10]. carried out a subjective assessment of a projected WF by means of Immersive Virtual Reality equipment. Different WF configurations were created in a real scale scenario and presented to individuals in order to evaluate the effects of three different components affecting the individual reactions: the distance, the number and the colour of the WTs. In the virtual presentation, participants experienced both the visual and the auditory stimuli from the WF: they were surrounded by a typical rural outdoor environment and could interact actively with it in a real time situation.

In this paper are presented two preliminary studies [11,12] performed recently by the Acoustic Group of the Second University of Naples and dealing with two questions of main concern for the WT noise impact:

1 - Are the maximum operating conditions, the worst operating condition for the WTs' noise perception?

2 - Are there differences in the recognition of WT's noise between people that are daily exposed to wind turbine noise (*chronic*) and those without any experience of exposure to this type of noise (*non-chronic*)?

In the first study [11] an objective approach was used by means a statistical analysis of the noise and of the meteorological measurements; in the second one [12], two groups of subjects, *chronic* and *non-chronic*, were involved to compare their differences in the capabilities to recognize the WTs noise by means of an auditory test (subjective approach),  
The studies were performed in two different sites in Italy where a WF plant was installed.

## METHODS AND MATERIALS

The selected "Site 1" was a WF in Savignano Irpino (Italy) and it was proposed an analysis to detect the impact of different functioning condition of the WTs by long term measurements [11]. A cluster analysis was applied to the noise and meteorological long term measurements at an outdoor receiver point situated in the yard of a dwelling, at the distance of 200m from the closest REpower MM92 WT (2 MW, hub height 80 m) of the WF.

On the other hand, for the "Site 2", it was selected a WF in Montelongo (Italy) with a number of 20 WTs of 2MW. A preliminary auditory test was carried out [12] to verify if any difference in the detection of WT noise between two group of subjects could be found: the first group was selected among the residents living in the vicinity of WTs (*chronic group*), while the second group was selected among people who had never been exposed to such a noise (*non-chronic group*).

### "Site 1" Measurements

A sound level meter (SLM) supplied with batteries in a IP65 box, was used for the long-term noise monitoring. The SLM equipped with a ½" microphone (50 mV/Pa, class 1) and a double wind screen was positioned at 2m height, far from reflecting surfaces in the courtyard of a house in the mentioned site, Savignano Irpino (Figure 1). Every 10 minutes the overall sound equivalent ( $L_{eq}$ ) and the statistical ( $L_{50}$ ,  $L_{90}$ ,  $L_{95}$ ) levels, as well as their one-third-octave band spectrum, were logged. Additionally a Vantage Pro2 weather station was positioned at the same height, close to the microphone position. The average and the maximum wind speed, wind direction, temperature, humidity, barometric pressure and rainfall were logged in the same temporal interval. The measurement activities lasted about 1 month.



Figure 1 Measurement activities at the receiver point in Savignano Irpino

#### “Site 2” Measurements

Several sessions of recordings were made for the WF located in Montelongo (Figure 2). The WF is formed by 20 WTs, Several measurements, of about 10 minutes, were made at three distances from the closest WT: D1) less than 50 m; D2) at 250 m and D3) at 2.5 km. The recordings were made during day period, when the WTs were functioning at stable condition (15 rpm), the temperature at the ground was about 10 °C and the sky was clear. The WT noise was the main component of the soundscape and the background noise was represented exclusively by the interaction between the wind and the surrounding vegetation. From all the recording positions, WTs were visible by the operator. The recordings were made by means of a wind screened binaural headphones Sennheiser HDC 451 connected to a portable device M-Audio Microtrack 24/96. At the same time a recording of a calibration signal of 94dB at 1kHz, generated by a calibrator type CAL01 01dB Metravib was provided.



Figure 2 Two WTs of the WF in Montelongo



“Site 2” Setting of the auditory test

A set of 24 sound tracks of 10s were selected and post-processed from the audio recordings, eight for each distance (D1, D2, D3), so that three groups of sound tracks were defined: G1) Group of 8 sound tracks where the WT noise was clearly audible, as measured at D1; G2) Group of 8 sound tracks where the WT noise was masked by background noise of wind and the detection was barely appreciable, as measured at D2; G3) Group of 8 sound tracks where the WT noise was apparently inaudible, as measured at D3. Later, a 2AFC (two-alternative forced choice) auditory test was prepared using the PsychoPy software [13]. The test consisted of a brief introduction and of set of 24 routines presented to subjects in a balanced and randomized order. Every sound track was associated to a routine. Each routine consisted of: 1) a message, aimed to focus the attention of the subject on the listening (2.5s); 2) sound stimulus (10s) and 3) a question followed by a task: “Did you hear the wind turbine noise? Press ‘Y’ for ‘YES’ or ‘N’ for ‘NO’ on the keyboard”. The sound track reproduction was performed using a laptop and a set of headphone Sennheiser HD201 (Figure 3).



Figure 3 Subjective tests for *non-chronic* group (left) and *chronic* group (right)

## RESULTS

### Results of the objective approach (Site 1)

In order to detect and group the different functioning conditions of WTs a cluster analysis was carried out. The analysis was applied on the  $L_{95}$  values for each 1/3 octave band of the audible range for the nocturne and downwind conditions. The cluster analysis allows to identify different clusters, by mean of Ward's method, and to create theirs hierarchical classification by minimizing the variance of the values of  $L_{95}$  for each 1/3. In this way the clusters having nearly the same spectrum are identified. Six clusters, characterized by different spectra and different  $L_{95}$  value were identified. The  $L_{95}$  of the spectral contribution are shown in Figure 4. Then, each cluster was associated with the average and the standard deviation of the wind speed (Figure 5).

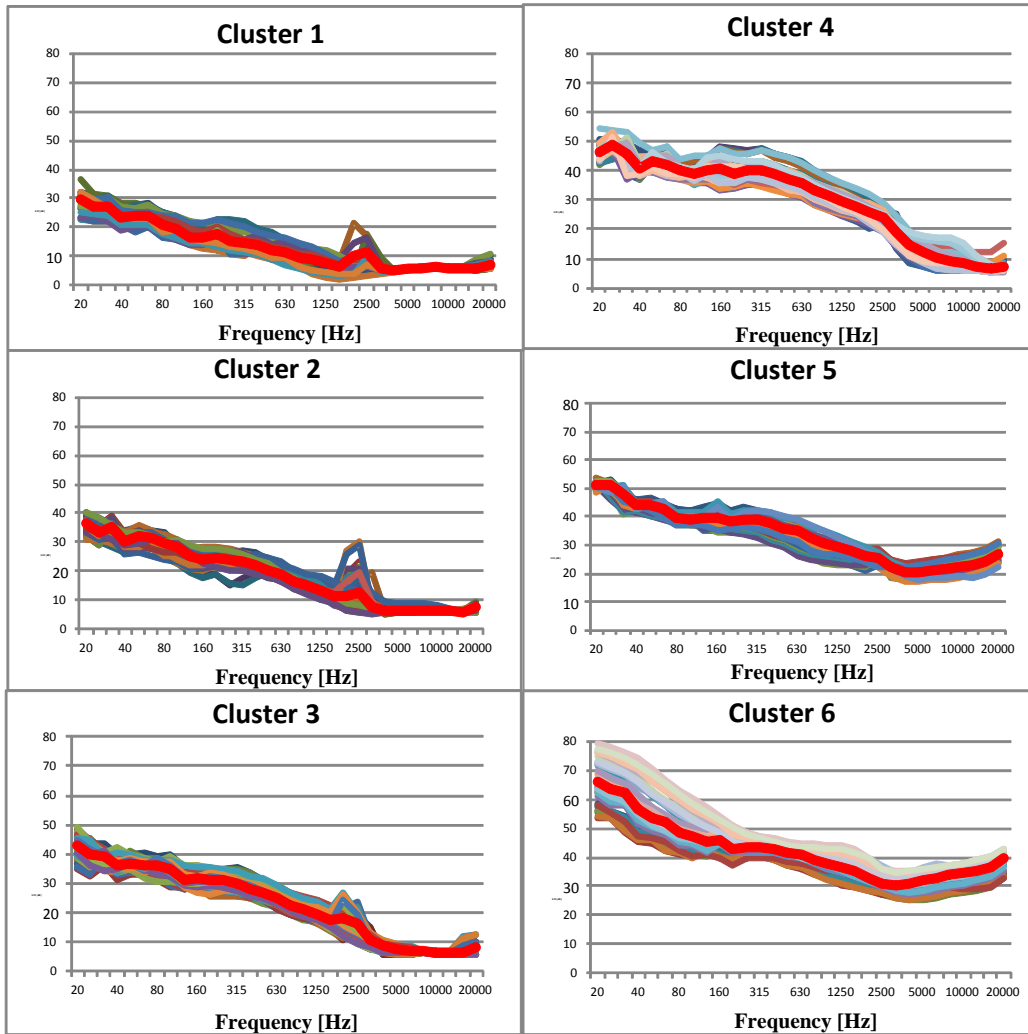


Figure 4 Clusters' spectral contribution of  $L_{95}$

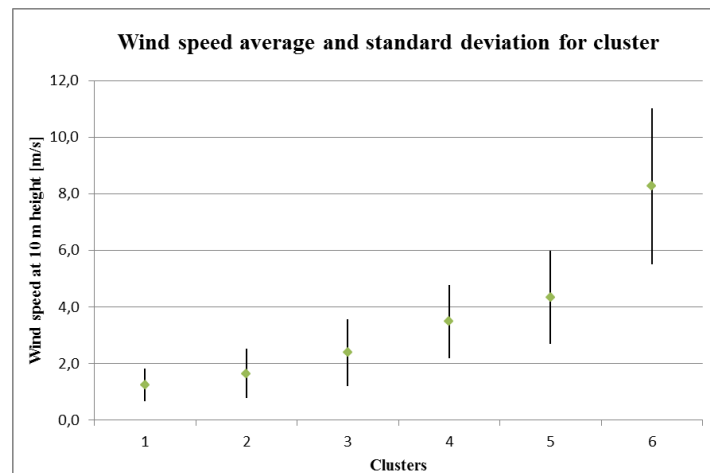


Figure 5 Average and standard deviation of clusters' wind speed

From the power curve of the WTs, it was possible to observe that the corresponding cut-in wind speed, at the height of 10 m, is estimated in 2.1 m/s (about 3.0 m/s at the hub). From this point, up to 8.3 m/s (about 12.0 m/s at the hub) the WT reaches the fully functioning condition.

From the Figures 4 and 5, it could be argued that the clusters 1, 2 and 3 were representative of "non-functioning" or "starting" conditions for WTs. For these clusters, in the frequency range 100-2500 Hz, a good logarithmic regression ( $R^2 = 0.94-0.96$ ) with an increase of the slope from -2.5 to -4.3 dB/octave band (from cluster 1 to cluster 3) can be detected (Figure 6).

On the other hand, the logarithmic regression curve (100-2500 Hz) for the cluster 6 presents an  $R^2$  coefficient of 0.97 while for the clusters 4 and 5 the  $R^2$  coefficients are less than 0.9. This suggested that, for highest wind speeds, the relative spectral contents can be comparable with the clusters 1-3, where the noise is caused by the wind sound.

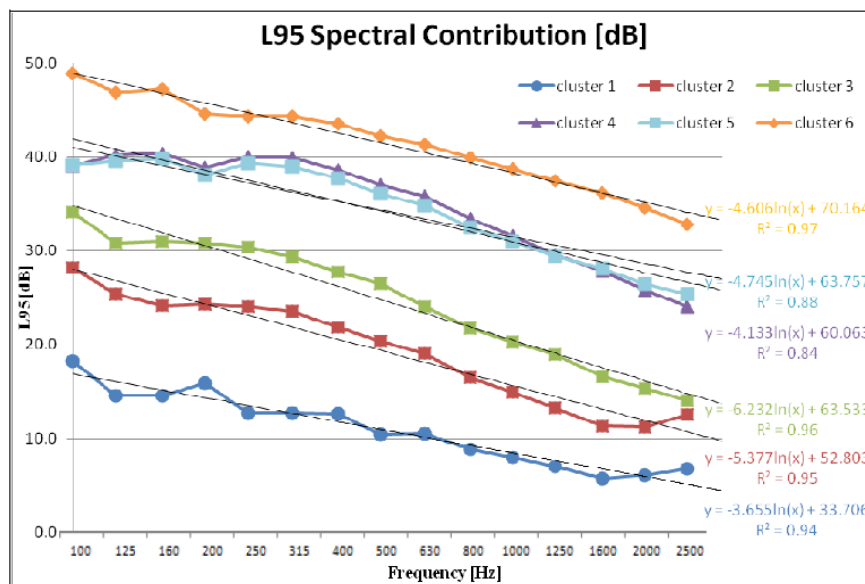


Figure 6 Clusters' spectral contribution of L95 with logarithmic regression

#### Results of the Subjective Analysis (Site 2)

The results of the test show that, compared with the non-chronic subjects, the chronic subjects are more inclined to recognize the WF noise. Globally 65.6% of their answers to the sound stimuli were positive (YES) while for the chronic subjects this percentage drops to 46.2%. With exception of sound track 1, this marked difference in the answers given by the two groups is evident also for each of the sound track stimuli (Figure 7).



Figure 7 Average of positive answers of chronic and non-chronic subjects, for each sound track

If the average answers are clustered in the three groups of sound tracks, the chronic subjects show a quite constant percentage of sound recognition, with a slight increase in G3, while for non-chronic subjects the percentage of positive answers decreases from G1 to G3. As a consequence, the differences among the positive answers of the two group of subjects increases: 16.2% in G1; 17.9% in G2 and 24.2% in G3, with the distance from the WF (Figure 8).

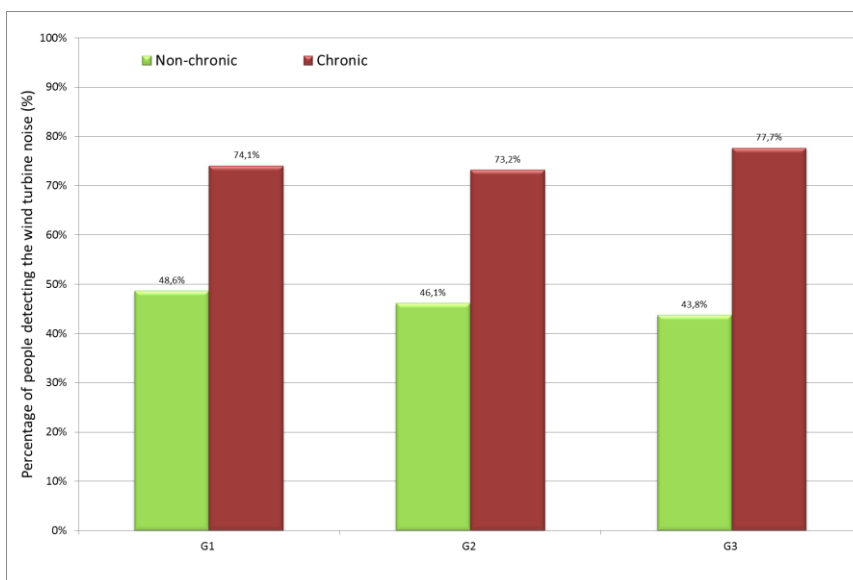


Figure 8 Average percentages of WT noise recognition of chronic and non-chronic, for the three group of sound tracks

## CONCLUSIONS

In this paper, by means of two preliminary studies, two different questions about the WT's noise impact were analyzed. Regarding the first question: "Are the maximum operating conditions, the



worst operating condition for the WT's noise perception?", synchronized measurements of noise and meteorological parameters were carried out and the results elaborated by a cluster analysis. Results showed that in the spectrum range 100-2500 Hz, a good logarithmic regression ( $R^2 = 0.94-0.96$ ) with an increase of the slope from -2.5 to -4.3 dB/octave band can be detected, when the wind speed are lower than the cut-in speed of the WTs. However, a similar behaviour is showed at the fully working condition of the WT ( $R^2 = 0.97$ ). This result suggest that, in this last condition, high wind speed could mask the main contribute at mid-frequencies of the WTs. On the other side, the analyses of the transient state (cluster 4 and 5) show that the behaviour is different and the values of the regression coefficient became, for these conditions lower than 0.9. In these cases the noise contribution of the WTs, at the mid-frequencies, lends a specific character to the WT noise, making it more recognizable.

On the other side, for the second question: "Are there differences in the recognition of WT's noise between people that are day by day exposed to wind turbine noise (*chronic*) and those without any experiences of exposure to this type of noise (*non-chronic*)?", the individual responses to the listening tests were considered: chronic subjects seem to be more inclined to recognize WT noise rather than non-chronic. The difference between the two groups increases as the distance increases. This result could be associated to both physical and psychological aspects: chronic subjects are daily exposed to this type of noise, becoming more expert and/or more sensitive; on the other hand, the answers of non-chronic subjects are free of preconceptions toward this sound source.

## REFERENCES

- [1] M.A. Nissenbaum, J.J. Aramini, C.D. Hanning, Effects of industrial WT noise on sleep and health. *Noise and Health* (2012), 60(14), 237-243
- [2] L.D. Knopper, C.A. Ollson, Health effects and wind turbines: A review of the literature. *Environmental Health* (2011), 78(10)
- [3] B. Thorne, The Problems With "Noise Numbers" for Wind Farm Noise Assessment. *Bulletin of Science Technology & Society* (2011), 31, 262-290
- [4] K. Persson Waye, E. Öhtröm, Psycho-acoustic characters of relevance for annoyance of wind turbine noise. *Journal of the Sound and Vibration* (2002), 250(1), 65-73
- [5] M. Masullo, G. Iannace, S. Basturk, F. Ruotolo, V.P. Senese L. Maffei (2011) The influence of vision on noise annoyance evaluation of wind farms. *Proceedings of the 4<sup>th</sup> International Meeting on Wind Turbine Noise, Rome; Italy, 2011*
- [6] E. Pedersen, P. Larsman, The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. *Journal of Environmental Psychology* (2008), 28, 379-389
- [7] S. Ljunggren, Recommended Practices for Wind Turbine Testing – 10. Measurement of Noise Immission from Wind Turbines at Noise receptor locations, Royal Institute of Technology, Stockholm, Sweden, 1997
- [8] D. Hessler, Accounting for Background Noise when Measuring Operational Sound Levels from Wind Turbine Projects. *Proceedings of the 4<sup>th</sup> International Meeting on Wind Turbine Noise, Rome; Italy, 2011*
- [9] E. Pedersen, K. Persson Waye, Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments. *Occupational and Environmental Medicine* (2007), 64, 480-486
- [10] L. Maffei, T. Iachini, M. Masullo, F. Aletta, F. Sorrentino, V.P. Senese, F. Ruotolo, The Effects of Vision-Related Aspects on Noise Perception of Wind Turbines in Quiet Areas. *International Journal on Environmental Research and Public Health* (2013), 10, 1681-1697
- [11] M. Masullo, F. Sorrentino, G. Ciaburro, Noise and meteorological monitoring of a wind farm. *Proceedings of the AIA-DAGA 2013 Conference, Merano, Italy, 2013*
- [12] L. Maffei, M. Masullo, M. Di Gabriele, N.E.P. Votsi, A preliminary investigation on some psychological and acoustic aspects of wind farms' noise annoyance. *Proceedings of the Internoise 2013, Innsbruck, Austria, 2013*

[13] J.W. Peirce, PsychoPy-Psychophysics software in Python. Journal of Neuroscience Methods (2007), 162(1-2), 8-13